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POSSIBILITIES OF THE TELESCOPE.

BY ALVAN G. CLARK.

WHAT the telescope of the future can do, may be partly learned from a comparative survey of its past history and progress. When Galileo in the early part of the seventeenth century showed his first telescope, which magnified only three diameters, to the astonished authorities of Venice, little did they dream of the possibility of the Lick refractor of to-day.

Galileo's first instrument was similar in construction to the ordinary opera glass. It was no more powerful, and was far less perfect. In fact, it consisted merely of two single lenses, one being convex and the other concave. Even his last and best telescope, magnifying thirty diameters, was much inferior to some of our spy-glasses. But even with this small instrumental equipment a new world was unveiled. He saw the spots on the sun, the phases of Venus, the mountains of the moon, the satellites of Jupiter, the rings of Saturn, and thrust back the barriers of the stellar world.

It may be remarked that there are two general classes of telescopes, the refracting and the reflecting. Much success has been attained by the Herschels, Lassell and others in the construction of reflecting telescopes, but as the refractor has proved itself the superior and as its possibilities for the future are, in my opinion, much greater, I shall confine myself principally to that.

The refracting telescope is composed of two principal parts, the object glass and the eye glass. The object glass has a general convexity of form, and its purpose is to collect light from the object and bring it to a focus near the eye glass, where it forms a bright image. The eye glass, in its turn, magnifies this image and renders it visible to the eye on an enlarged scale. But in order to enlarge the image we must collect considerable light, and

the more we magnify or spread out this image the more light we must collect to render it visible, and consequently the greater object glass, or light collector, we must have. Hence it was that simultaneously with the first telescopes arose the desire to get more light in order to obtain a greater magnification.

Two difficulties, however, presented themselves ; first, that a single convex lens will not accurately converge all the rays of light to the same focus, and, second, that a single lens, acting as a prism, disperses the rays, thus giving a series of overlapping images of different colors. The first is called spherical and the last chromatic aberration.

In order to increase the power of the early telescopes, recourse was had to larger single lenses of great focal length ; but this only partly obviated the difficulty, and it rendered them very unwieldy. About 1758 Dollond found that if the object glass was composed of two lenses of different kinds of glass, and of the proper form, instead of one, both aberrations could be corrected. It is by this principle that the modern achromatic telescope has been made possible.

But the main question of this article is : What are the future possibilities of the telescope, and what is the limit to its size ; also, what will the great telescopes of the future do ? We answer that there is practically no limit to its size, the reason for our answer being contained partly in what has already been said, and partly in what will follow.

For centuries men studied the heavens more or less successfully without the aid of telescopes. Gradually, however, the standard of observation was raised, but with the invention of the telescope a tremendous advance was made. Hitherto, men's observations were confined to the limits of ordinary vision. Not a single observation could be obtained beyond it. With the advent of the telescope, however, the horizon of knowledge was greatly enlarged even at the outset. Then came the desire for greater power, and to obviate the difficulty in the single lens system, long unwieldy instruments were constructed. Still farther advances were made possible by the invention and use of the double achromatic lens, by means of which the aberrations could be corrected and the telescope reduced in length to a convenient size. Then, another difficulty presented itself, to procure discs of glass which would be free from veins and striae, and at

the same time homogeneous. Even towards the close of the last century it was impossible to secure suitable pieces of glass of more than six or seven inches in diameter, and these were often of a very inferior quality.

When, in 1825, the Dorpat refractor of nine and a half inches aperture was constructed, it was considered a masterpiece, and it was thought the limit had been reached. Guinand, however, had made better glass possible, and Fraunhofer better workmanship. As a consequence, there were constructed in 1845 two object glasses of fifteen inches aperture. But this limit was again surpassed when we succeeded in procuring discs for an eighteen and three-quarter inch glass, which were figured and sent to Chicago. Then followed the twenty-six inch lenses of the Washington and McCormick observatories, the thirty inch lens of the Pulkowa, and, finally, the great thirty-six inch lens of the Lick observatory.

It must be remembered that the ground had been disputed inch by inch, and that with each succeeding advance the limit of successful glass melting was thought to have been attained. Even quite recently a noted optician, speaking of the possibility of obtaining discs larger than thirty-six inches, said it appeared to him that the chances of obtaining forty inch discs in the present state of the art were remote. And yet there are now in my manufactory two remarkably fine discs of forty inches diameter ready for figuring. Who then shall set the limit to this phase of the art, considering the great possibilities of scientific improvement and advance of the present day, in view of what has been already accomplished?

But some one will ask : "How about giving a correct figure to such enormous lenses?" When one considers that all the rays of light passing through these great lenses must be brought to a focal point which a thread would far more than cover, and that the aberrations must be corrected at the same time, this question is not inapt. But I venture to say that by my method of local correction, lenses of any size can be figured and brought into shape with comparative ease. I do not mean to assert that the undertaking is not a great one, but it will, nevertheless, be crowned with success.

This method of local correction consists, in general terms, in first finding the defects of a lens by frequent optical tests during the process of figuring, and then eliminating them without intro-

ducing others, by work at those points, the finest and most delicate work being done with the fingers. In this way a lens can be corrected wherever it becomes necessary, until absolute perfection is given to the image, and it is only by this method that I have been able to secure uniformly good results. With the monster telescopes of the present and future, however, the workmanship must, if possible, be even more critical, for, from the great size of the lenses any inherent difficulty will be still more aggravated. It may be, however, that the glass is not uniformly homogeneous, and that there is a slight increase in density over a small area of its surface. In this case by the method I have advocated, an excess of polishing and abrasion may be used at this point, the lens slightly flattened, and a perfect image secured. By this means the optician can render himself to a certain extent independent of the skill of the glass manufacturer, and a great disc with even a slight imperfection could be made to give a perfect result.

A question sometimes asked is: "Will not a great increase in the size of lenses necessitate so much increase in thickness that a large amount of light will be lost by absorption?" In reply, I would say, that we are a long way from experiencing anything very serious in this respect. The forty inch discs, already mentioned, have only a combined thickness of some four inches, and the lenses of an object glass of even six feet aperture would necessitate a combined thickness of not more than six inches. To be sure this increased thickness means some more absorption, but not to the extent that some suppose, especially with the best glass now obtainable.

An experiment made at my manufactory will perhaps best illustrate just what I mean. I took a block of dense flint glass nine inches thick and polished on both edges. Behind this was placed common newspaper print, while in front of it sat a party who ordinarily, although not invariably, used glasses in reading. Through this nine inches of dense glass, however, he was able with perfect ease to read the whole newspaper article by lamplight, and without optical aid. But this nine inches in thickness is, as I have already said, much more than is necessary for even a six foot lens, and who knows how soon still more transparent glass may be at hand, considering the steady improvement made in this line, and the fact that the present discs are infinitely superior to the early ones.

But even supposing a slightly larger per cent. of light is lost by absorption per unit of surface in a six foot lens than in a three foot one, yet the area of the larger will be four times that of the smaller, so that the total amount of light must be vastly greater.

Besides, every one who has had experience in using telescopes knows, that even if two instruments of quite different sizes can both see the same object without trouble, the larger one has a decided advantage from the greater amount of light and the consequent increased ease and facility of seeing, which enables us to do better work. In illustration of the great light-collecting power of a large telescope, I may cite the fact that with the thirty-six inch refractor, eighteen nebulae were discovered at the Lick observatory in a space only 16' by 5'.5, and, more recently, a fifth satellite has been added to the planet Jupiter.

As regards the possible bending of great lenses under their own weight, although this sometimes occurs in a small degree, both sides are affected in a nearly compensatory manner, while in a mirror there is no such compensation. Any slight imperfection at any point on the surface of the lens, whether from defective workmanship or bending of the lens itself, produces much less error in the image than in the case of a reflector. The slightest imperfection of workmanship or distortion of the mirror from its own weight, as well as any difference of temperature between the front and back, will utterly ruin the image, while the performance of a lens would be much less affected by the same circumstances. Partly for this reason, reflecting telescopes very rarely give any such definition as refractors.

Then again, the refractor will give a much larger per cent. of the incident light than the speculum metal reflector. I speak of speculum metal reflectors because the difficulty of preserving the reflecting silver film on large silvered glass mirrors is so great, and the process of resilvering becomes so formidable, that I believe them to be impracticable.

From what I have said, as well as from other considerations, which it is not necessary to mention here, I have not the slightest doubt that our future advance must be along the line of the refracting telescope.

Until a comparatively recent date wooden tubes were used for telescopes, but these being sluggish as regards equalization of temperature, a star image was often defective and showed wings

before all the parts of the telescope had acquired the same temperature. This defect, however, has been completely eliminated by the introduction of the metallic tube, which, with a minimum amount of weight, gives a maximum amount of stiffness and produces uniformity of temperature very rapidly.

But, in order that the object glass, as its size becomes so great, should also rapidly assume and constantly maintain uniformity of temperature in all its parts, I have separated the crown and flint lenses in construction so as to allow a free circulation of air between them. In the Lick telescope this separation amounts to some six inches with holes in the sides of the cell, thus allowing a free circulation of air between the lenses.

Thus we have to-day a refracting telescope that has steadily grown in size with increasing perfection in all its parts, and which has, beyond question, a still greater future before it. What the pledge of the past has been, the future will fulfil. What, then, are the possibilities of accomplishment for these great telescopes of the future ?

We may answer that they will do great work anywhere, although much depends on the circumstances in which they are placed. For the finest work they should have good atmospheric conditions, but these may be obtained at various places throughout the world, both at ordinary as well as higher altitudes. When used under such conditions much will be added to our present knowledge of astronomy.

The great and rapid strides which have lately been made in astrophysics, principally in the line of photometry, photography and spectroscopy, added to the vast amount of work which will always remain to be done in the older astronomy of motion, opens a field for the most powerful means of research. These monster telescopes may be characterized as the great light-collectors and space-penetrators of the universe, and their province, the solution of the ultimate problems of science.

ALVAN G. CLARK.